STABILITY RELIABILITY OF HABITUAL PHYSICAL ACTIVITY WITH THE ACTICAL® ACTIVITY MONITOR IN A YOUTH POPULATION

by

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ABSTRACT

The purpose of this study was to examine and compare stability reliability of hip- and wrist-worn activity monitor (AM) physical activity (PA) outcome variables for adolescents (12-17 years) under free-living conditions. Twenty-one adolescents (11 girls, 10 boys) wore AMs at hip and wrist locations for a 14 consecutive day monitoring period. The dependent variables were total time (minutes/day) occurring at sedentary (T_S), light (T_L) and ≥ moderate (T_{MV}) intensity PA, and the sum of activity energy expenditure (AEE; kcals/day) occurring at a light (AEE_L), ≥ moderate intensity (AEE_{MV}) and from total AEE for a monitoring day (AEE_T). Intraclass correlation coefficients for each monitoring day (ICC_{DAY}) were calculated to examine reliability of all dependent variables for both AM locations, over bout durations of 1-, 5-, and 10-minutes. Excluding T_L measured by the wrist AM location, ICC_{DAY} values for all variables decreased as bout duration increased from 1- to 10-minutes. The number of monitoring days to reach an $ICC_{DAY} \geq 0.80$ for AEE_L, AEE_{MV}, AEE_T, T_L and T_{MV} across all three bout durations was higher for hip- versus wrist-worn AM, and ranged from 2-26 versus 2-10 days, respectively. Conversely, then number of monitoring days to reliably measure T_S was lower for hip AM (4-5 days) versus the wrist AM (6-8 days) locations. Among all the variables, T_L had the largest range of necessary monitoring days to reach an $ICC_{DAY} \geq 0.80$, 7-10 and 6-26 days across all bout durations for the wrist and hip, respectively. Further comparison of the dependent variables by day type revealed that only T_L measured at the wrist had significantly different means on weekdays versus weekends (p-value ≤ 0.001) across all bout durations. While not significant, mean values for T_{MV}, AEE_{MV}, and AEE_T measured by both hip- and wrist-worn AMs, were higher on weekdays than on weekends. In summary, reliability of time and AEE PA variables was dependent on bout duration and AM location. Generally, to reliability measure free-living PA in adolescents wrist-worn AMs required fewer monitoring days than hip-worn AMs.

CHAPTER ONE

INTRODUCTION

Obesity is of paramount concern for children in the United States. Since the 1980's the prevalence of childhood obesity has more than tripled in the US (National Center for Health Statistics (NCHS) 2010). Although results of the 2007-2008 National Health and Nutrition Examination (NHNE) survey suggest that the progression of obesity incidence has leveled off, the occurrence of childhood obesity remains alarmingly high. Data suggests 31.7% of children (2-19 yrs) are categorized as being overweight, and of those children that are overweight 16.9% are classified as obese (Ogden et al. 2010). Overweight is defined as having a Body Mass Index (BMI, weight in kilograms divided by height in meters squared) $\geq$ the 85th percentile, and obese is having a BMI $\geq$ the 95th percentile for a child's age and gender when compared to Centers of Disease and Prevention (CDC) growth charts (Ogden et al. 2006).

Mirroring the rise of childhood obesity is the increase of chronic disease risk in children. Chronic diseases and co-morbidities traditionally associated with obesity in adults are being identified in children. Dyslipidemia, cardiovascular risk factors, insulin resistance, and type-2 diabetes have been observed in obese children (Tracy et al. 1995; Sinha et al. 2002; Arslanian 2002). Research has begun to show that obesity in childhood can impact an individual's health into adulthood, further pressing the need to address the issue of childhood obesity (Baker et al. 2007).

Prevention and intervention methods aimed at reducing levels of obesity have focused on increasing levels of habitual physical activity (PA). Physical activity is defined as any bodily movement produced by muscular contractions that increase energy expenditure (EE) above that of resting levels (Caspersen et al. 1985). The participation in habitual PA can lead to the prevention of chronic illnesses such as cardiovascular disease, diabetes, and obesity in both children and adults (Warburton et al. 2006; Pate et al. 1995). The Department of Health and Human Services sought to place importance on the relationship between health and PA with the publication of the 2008 Physical Activity Guidelines for Americans. The guidelines for children and adolescents recommend at least 60 minutes of PA daily, which can be a combination of aerobic, muscle-strengthening, or bone-strengthening activities. Emphasis is placed on aerobic activity, citing 60 or more minutes a day should be accumulated from either moderate- or vigorous-intensity aerobic activity, including vigorous intensity on at least three days of the week (US Department of Health and Human Services [USDHHS] 2008). Although government and professional agencies have made public recommendations based on scientific evidence, the implementation of PA recommendations is lagging. The importance of an objective measure of free-living PA is vital to the understanding of the behavioral hurdles that may compromise participation in habitual PA.

There are a variety of methods used to monitor PA. Four main categories of PA monitoring exist: subjective reports, doubly-labeled water, calorimetry, and portable monitors (Chen and Bassett 2005). Subjective measures such as self reported activity logs and surveys, which have been utilized in adults, may be inappropriate for use in children.

Factors that complicate the process of recall in surveys and activity logs for children are participation in activities which are sporadic and vary in intensity (Armstrong and Bray 1991; Bailey et al. 1995; Sirard and Pate 2001). While methods such as doubly-labeled water and calorimetry remove the need for recall and are considered effective methods to assess the energetic cost of physical activity, both methods can be expensive, intrusive and time-consuming (Dishman et al. 2001). Monitoring methods such as direct observation, pedometers, heart rate monitors, and accelomertry-based activity monitors (AMs) are effective methods for monitoring PA and have been used in youth populations. For example, Pate and colleagues recently suggested that the combined method of direct observation and accelerometry offer measurements of intensity and durations as well as contextual information about the activity being performed (Pate et al. 2010). The use of electronic AMs has gained the interest of researchers in the field of physical activity. Improvements in AM technology have led to decreases in monitor size, and allowed for marked increases in data storage capacity. As AMs become smaller and more capable of long-term monitoring, the feasibility of using AMs to monitoring free-living PA has greatly increased.

Accelerometry-based AMs are wearable monitors that measure acceleration magnitudes experienced by the body during PA. Activity monitors utilize a piezoelectric element and a seismic mass to detect acceleration in one to three planes (anteroposterior, mediolateral, and vertical). Acceleration from body movement causes the seismic mass to deform the piezoelectric element, with a resultant change in voltage that is stored as “raw counts” (Chen and Bassett 2005). The raw counts are then transformed with the use of

algorithms to PA counts for a specific amount of time or epoch length. These PA counts are then analyzed to determine estimated EE and time spent in different exercise intensities. When considering the need to understand behavioral choices of exercise, EE and time spent at specific intensities allows for an objective comparison of the observed behaviors to current PA guidelines.

The use of AMs to study free-living PA has primarily focused on adults where the devices have been established as valid tools of measurement (Ward et al. 2005). However, with current trends in childhood obesity research has concentrated on the use of AMs in children. Recent research within the youth population has focused on the calibration and validation of various commercial AMs. Calibration of the monitors has included activities of walking or running on a treadmill, and a variety of free-living activities (Freedson et al. 2005). Criterion measures such as direct and indirect calorimetry, as well as heart rate have been used to assess the validity of AMs to accurately measure PA outcome variables (Janz 1994; Trost et al. 1998; Pate et al. 2006). Several studies have reported acceptable validity of AMs, allowing for AMs to be established as valid tools for the assessment of PA in children (Puyau et al. 2004; Freedson et al. 1998; Trost et al. 1998; Heil 2006; Pfeiffer et al. 2006).

Due to the increased use of AMs for assessing physical activity in children, there is a need to establish best practices for data collection in this population. One parameter to consider is monitoring duration. Physical activity is often monitored with the intention of observing trends in habitual PA. In order to know if the PA data can be considered habitual, stability reliability of the instruments' outcome variables must be considered.

Stability reliability refers to the variability in measurements from day-to-day (Atkinson and Nevill 1998). When the duration of a monitoring period is too short, stability reliability can be low and the estimation of habitual PA poor. The stability reliability of PA outcome variables can be affected by such factors as leisure versus occupational settings, the population being studied, funding and personnel resources, as well as the research question itself (Ward et al. 2005; and Trost et al. 2005). A review by Trost and associates reported the days needed to achieve an acceptable intraclass correlation (ICC) of 0.80 ranged from four to nine days. Thus, it was recommended that a minimum 7-day AM monitoring period be used when studying free-living PA in children (Trost et al. 2005).

The location the AM is worn during a monitoring period is a second parameter that may impact the quality of data. The hip has been established as the most common site for the device during monitoring in both children and adult populations (Ward et al. 2005; Trost et al. 2005). Traditionally, the hip has been used because it allows acceleration to be measured near an individual's center of mass. When monitors are worn at the hip they are frequently taken on and off throughout the monitoring period which may lead to complications in subject compliance. The degree to which this problem exists is unknown because there is a tendency for researchers to under report compliance problems experienced with data collection (Heil in press). In order to improve long-term wearing compliance, the validity (Heil, Bennett, Bond, Webster and Wolin 2009) and stability reliability (Webster and Heil 2008) of wrist-worn AMs to measure free-living physical activity have been evaluated in adults. However, as demand grows to expand the

use of AMs in children similar research must be established for PA monitoring in youth populations.

The Actical ® activity monitor (Philips Respironics, Inc., Bend, OR, USA) is an AM which has been calibrated and validated for measuring PA of children at wrist- and hip-worn locations (Heil 2006). While stability reliability for measuring free-living PA with the Actical® monitor has been established for wrist- and hip-worn monitors in adults (Webster and Heil 2008) the monitor's stability reliability for long term wearing by youth has not yet been established.

Statement of the Purpose

The purpose of this study was to examine and compare the stability reliability of hip- and wrist-worn Actical® activity monitor PA outcome variables in adolescents (12-17yrs) under free-living conditions.

Hypothesis

The null hypothesis was that no differences would be observed between stability reliability of free-living PA outcome variables for hip- and wrist-worn Actical® accelerometers for a given number of monitoring days. The alternative hypothesis was that stability reliability of free-living PA outcome variables for hip-worn Actical® accelerometers was greater than wrist-worn accelerometers for a given number of monitoring days.

$$H_O: R_h = R_w$$
$$H_A: R_h > R_w$$

Where R_h is the mean reliability measurement of the physical activity variables: total time in minutes spent in sedentary (T_S), light (T_L) and ≥ moderate (T_{MV}) intensity and activity energy expenditure from light (AEE_L), ≥ moderate intensity (AEE_{MV}) and total physical activity (AEE_T) for the hip-worn activity monitor. The variable R_w is the mean reliability measurement of T_S, T_L, T_{MV}, AEE_L, AEE_{MV}, and AEE_T for the wrist-worn monitor.

Assumptions

1. The equation used to calculate intraclass correlation coefficients (ICC) assumes that the variance for each monitoring day is equal, and is based on the variance scores calculated for the total number days in the monitoring period.
2. Any weekday (Monday – Friday) was representative of a typical weekday, and Saturday, Sunday and a holiday (Presidents Day) was representative of a weekend day.
3. It was assumed that the field validity of the Actical® AM to measure free-living PA in adolescents was similar to the results reported in an adult population (Heil, Bennett, Bond, Webster and Wolin 2009).
4. It was assumed that the smoothing algorithm previously applied to AM data in adults (Heil, Hymel, and Martin 2009) could be applied to AM data for adolescents.

Limitations

1. The number of monitoring days for the study was limited to 11 days due to memory saturation of the AM.
2. Not all subjects started monitoring on the same day of the week, while all subjects have 5 weekday and 2 weekend days (Days 1-7) not all additional days of the monitoring period (Days 8-11) are similar between subjects.
3. The hip-worn AMs were removable, thus the hip monitor data was limited to the times that a participants actually wore the monitor.

Delimitations

1. The scope of this study was delimited to the winter season and climate of Bozeman, MT.
2. The study population was delimited to adolescents (12-17 years) from the greater Bozeman, MT area.

Operational Definitions

Physical Activity:	Any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above that of resting levels.
Activity Monitor:	A device used to estimate physical activity outcome variables through measurements of acceleration experienced by the body.
Bout Duration:	A defined amount of time when an individual is participating in a given intensity.

Energy Expenditure: Total kilocalories expended to complete a task (kcals).

Free-living: Participation in daily activities in a normal manner when in a field setting; where no instruction or constraints are imposed by the investigator.

Stability Reliability: A type of reliability that refers to the variability in measurements from day-to-day.

Monitoring Day: A period of 10 consecutive hours where physical activity is being recorded by an activity monitor.

Activity Energy Expenditure: Relative energy expenditure to perform a task above resting (kcaks/kg/min or kcals/day).

Total Time in Sedentary Physical Activity (T_S):

The sum of time (minutes) for a monitoring day classified as occurring at a sedentary intensity.

Total Time in Light Physical Activity (T_L):

The sum of time (minutes) for a monitoring day classified as occurring at a light intensity.

Total Time in Moderate to Vigorous Physical Activity (T_{MV}):

The sum of time (minutes) for a monitoring day classified as occurring at or above a moderate intensity.

Activity Energy Expenditure from Light Physical Activity (AEE_L):

The sum of AEE values for a monitoring day classified as occurring at a light intensity.

Activity Energy Expenditure from Moderate to Vigorous Physical Activity (AEE_{MV}):

The sum of AEE values for a monitoring day classified as occurring at or above a moderate intensity.

Activity Energy Expenditure from Total Physical Activity (AEE_T):

The sum of AEE values for a monitoring day.

CHAPTER TWO

REVIEW OF LITERATURE

Introduction

A key to understanding childhood obesity is the ability to examine habitual patterns of free-living PA in youth. In order to develop and evaluate PA interventions, researchers must have a clear understanding of current PA behavior. When PA can be objectively measured it allows for a better understanding of the dose-response benefits associated with exercise, and how participation with current PA guidelines contributes to health. Activity monitors offer an objective, valid, and reliable measurement of PA and are becoming increasingly popular tools in research settings.

There are several characteristics of PA behavior that should be considered when measuring habitual free-living PA with AMs. Due to the variable nature of day-to-day PA patterns, the number of days necessary to reliably measure habitual PA must be considered. Additionally, the location the monitor is worn will result in different reliability measurements of PA outcome variables. Therefore, when using accelerometry-based AMs for research, consideration should be placed in the reliability of measurement variables, number of monitor days necessary to achieve acceptable reliability, and monitor placement on the body.

Reliability

When considering various testing methods and devices used in research settings, the evaluation of the method's reliability is critical. Reliability is a measurement of the amount of error variance that is found in a set of data (Portney and Watkins 2009). Much research relies on the evaluation of an observed set of measurement values to further the establishment of knowledge. The variation between observed scores is considered to be the sum of the variance associated with the true score and the variance associated with the error score, hence the general term of reliability refers to the ratio of the true variance to the total variance (Portney and Watkins 2009). In terms of the evaluation of repeated observations it is anticipated that the true score remains the same and that any variation within the observed set of values is a result of the error score. The reliability coefficient, which refers to the ratio of true variance to total variance, is a value between zero and one. When the coefficient is 0.0, it indicates that all the variation seen in the observed score is due to the error score, whereas when the value approximates 1.0 the variation in the observed score is associated with the variance that is inherent with the true score (Portney and Watkins 2009). There is always a component of innate error in measurements of variables; reliability allows for an objective and critical evaluation of what level of error is acceptable for the measurement to have a practical use (Atkinson and Nevill 1998).

There are several different methods to calculated reliability such as correlation coefficients, the coefficient of variation (CV), the standard error of measurement (SEM), and the intraclass correlation coefficient (ICC) (Atkinson and Nevill 1998). Generally,

reliability can be split into two categories, relative reliability and absolute reliability. Measurement methods that assess relative reliability take into consideration how the observed variable changes position in comparison to all the measurement of similar variables over multiple trails, or the observed variable's relative position within the group. Types of methods that calculate relative reliability are correlation coefficients and the ICC.

Correlation coefficients are a measure of the association found between two sets of repeated measurements. High correlation coefficients, those that approach one, are considered to have a strong association thus are determined reliable. Although the correlation coefficient assesses the relative change of position within the group, it lacks the ability to detect changes in agreement of the measuring variables between repeated measures. Portney and Watkins (2009) provided an example of this limitation by giving two sets of numbers, 1:1, 2:2, 3:3, 4:4, 5:5 and 1:6, 2:7, 3:8, 4:9, 5:10. Both sets of numbers have perfect association, meaning that the relative position of the data remains the same between the number sets. In terms of correlation coefficients this would indicate high reliability. However, even though the two sets of numbers have perfect association, they are not in agreement with each other due to an absolute increase in the second number set (Portney and Watkins 2009).

The ICC is a second measurement of relative reliability. Intraclass correlation coefficient values are calculated from variance estimates retrieved from an analysis of variance, and range in value from zero to one (Portney and Watkins 2009). Although there are variations of calculating ICC values, generally the ICC is a ratio of the variance

associated from the true score to the total variance, where total variance is a function of both random error and systematic error (Weir 2005). The ICC improves upon correlation coefficients as a measure of reliability because it takes into account the relative association between variables and can be calculated to be sensitive to systematic bias or the agreement between variables (Atkinson and Nevill 1998).

Absolute reliability takes into account the relative change in position of the variable in comparison to the group of data; however, it also considers the absolute change between measurements. The interpretation of absolute reliability measurements are in the same scale as the measurement variable or unit-less, thus allowing for easier interpretation to the original data (Portney and Witkins 2009). The CV uses the standard deviation of the observations to calculate reliability. The standard deviation of the responses is assumed to reflect of the degree of measurement error associated with the observations. The CV is calculated by dividing the standard deviation by the mean of the observed groups and multiplying by 100. The CV is a unit-less measurement because the units of standard deviation and the mean are the same, thus they cancel each other out. This makes the CV a measurement of reliability that can be compared between repeated measures and even different studies (Portney and Watkins 2009).

The SEM is a measurement of variability between repeated observed scores; it accounts for the absolute stability and the precision of repeated measures (Portney and Watkins 2009). The SEM is calculated by taking the standard deviation from all scores of subjects and multiplying it by $(1 - ICC)^{-1/2}$ (Weir 2005). The SEM is based on the assumption that within repeated tasks there is a natural variability or error associated with

the variable being measured. Due to the natural variability, plots of the observed scores will approximate a normal distribution, where the true score is represented by the mean and the error scores falling above or below the mean. If the measurement of reliability is high, the SEM would be low and the observed score would fall close to the mean, where as if reliability was low the SEM would be higher and fall further from the mean (Portney and Watkins 2009).

In the field of PA monitoring, the measurement of reliability can refer to the measurement instrument such as an AM, or it can refer to the reliability of observed behaviors of individuals. The term test-rest reliability refers to the measurement of consistency of a measuring device (Portney and Watkins 2009). Test-retest reliability can be separated into two categories, inter- and intra-instrument reliability. Inter-instrument reliability, often termed technical reliability refers to the ability of the same type of instruments to consistently measure the variable of observation (Esliger and Trembaly 2006). Metcalf and associates examined the technical reliability of a uniaxial AM, by simultaneously stimulating 25 AM on a turntable spinning at medium and high speeds. For both speeds ICC values ranged from 0.71 to 0.99 (Metcalf et al. 2002). More recently, the technical reliability of AMs was investigated by using a hydraulic shaker to simultaneously stimulate three different types of commercially (triaxal, uniaxial, and omnidirectional) available AMs. It was reported that the AMs inter-instrument reliability in ICC values from 0.91-1.0 (Esliger and Trembaly 2006).

Intra-instrument reliability refers to the ability of a single measuring device to consistently measure the variable of interest over multiple trials. The intra-instrumental

reliability has also been assessed in accelerometry-based AMs. Intra-instrument reliability of AMs can be assessed by performing repeated locomotion tasks while wearing the same AM between trials (Welk et al. 2004; Howe et al. 2007). For example, Howe et al. (2007) examined the intra-instrument reliability of an omnidirectional accelerometry-based AM. Monitors were worn on both right and left hips, and wrists. Participants performed three trials of locomotion at six different walking speeds. The ICC values for all monitoring locations and walking speeds for all three trials ranged from 0.97 to 0.99.

The reliability of an individual's behavior or performance over time is often measured in human research. In the field of activity monitoring, interest is placed on the ability to measure a true estimate of habitual free-living PA behavior (Trost et al. 2005). Stability reliability refers to the type of reliability which allows for the assessment of day-to-day variability (Atkinson and Nevill 1998). The evaluation of stability reliability of PA variables for a single day of monitoring, and the evaluation of increased reliability associated with each additional day of monitoring, allows the requisite number of monitoring days to be determined.

Stability Reliability of Monitoring Days

The number of monitoring days necessary to achieve reliable measurement of free-living PA variables has been studied for hip-worn accelerometry-based AMs in various populations (Coleman and Epstein 1998; Janz et al. 1995; Mattocks et al. 2008; Trueth et al. 2004; Trost et al. 2000; Trueth et al. 2003). To establish best practices for number of

monitoring days necessary to achieve an acceptable level of reliability for hip-worn AMs, Trost et al. (2005) recommended 3-5 consecutive monitoring days for adults and 4-9 consecutive days for youth. This recommendation outlines different ranges of monitoring days necessary to achieve acceptable reliability for measurement of habitual PA variables in adults and youth. The range of recommended monitoring days is a composite of recommendations reported by multiple studies, differing in population parameters and methodological choices made by researchers. When choosing the number of monitoring days it is important to consider factors that affect the stability reliability of physical activity variables.

Population specific factors which may alter the number of necessary monitoring days are subject age, type of days within the evaluation period (i.e., weekend versus weekday), and seasonal variation of physical activity. When considering the general recommendations by Trost et al. (2005) for the number of monitoring days, there were differences based on the age of the group being studied (i.e., adults or children). The difference in length of monitoring periods between adults and children was attributed to the innate differences in types of PA participated in by the two groups (Trost et al. 2005). The influence of age on the reliability of PA variables has also been investigated within different age ranges of youth. Trost et al. (2000) examined the stability reliability between adolescents (grades 7-12) and children (grades 1-6) for hip-worn accelerometry-based AMs, over a 7 day period. The ICC values for 7 days of monitoring ranged from 0.76 to 0.77 for adolescents and 0.86 to 0.87 for children. To achieve an ICC value of 0.80, 4-5 monitoring days were necessary in children, whereas 8-9 days were necessary

in adolescents. Clearly, age of the study population must be considered when determining the number of days AMs will be worn by participants.

A second factor to take into account when determining the monitoring period of a study is whether the monitoring period will include both weekdays and weekends. Studies in children have indicated a significant difference between habitual moderate to vigorous PA (MVPA) performed on weekdays versus weekends (Metcalf et al. 2002; Trost et al. 2000). Metcalf et al. (2002) reported that in healthy 5-year olds, PA during the school week was significantly lower ($p = 0.006$) than PA performed on the weekend. Trost et al. (2000) documented similar differences in habitual MVPA for children and adolescents between weekdays and weekends. Younger children were found to participate in significantly more MVPA on the weekends, whereas adolescence participated in significantly higher levels of MVPA during the week. Both of these studies indicated the need to define the type of days which constitute a monitoring period in order to determine if habitual PA can be reliably measured. However, it must be recognized that both of these studies were conducted during the school year, meaning that a large variation between weekdays and weekends may be associated with children's attendance of school throughout the week. Janz et al. (1995) showed that stability reliability for PA variables during the summer months was not significantly different between weekdays and weekends. The authors concluded that any day (Monday through Saturday) during the summer was representative of habitual PA in children.

Seasonal variation may also be a factor to consider when performing PA monitoring. The level of habitual MVPA in children has been shown to change

depending on the time of year (Mattocks et al. 2007). In this study by Mattocks and associates the stability of children's (7-15 yrs) PA was measured with accelerometry-based AMs. Participants wore AMs for seven consecutive days during four different periods of the year. An ICC = 0.53 indicated that the variation of habitual PA within individuals was related to the period of the year in which the measurements were taken. Thus, consideration of the season in which PA monitoring is taking place may be an important factor in considering the accurate assessment of habitual PA in children.

Although population specific factors need to be considered when using accelerometry-based AMs, there are also methodological decisions which may affect the stability reliably of PA variables. Stability reliability of PA variables may be affected by methodological factors such as the operational definition of acceptable reliability chosen by researchers. The operational definition for the acceptable level of reliability has produced multiple recommendations for the necessary number of monitoring days. Mattocks et al. (2008) provided an example of how the required number of monitoring days can change based on the variation of operational definition for acceptable reliability within the same groups of individuals. Three ICC values were chosen (ICC = 0.7, 0.8, 0.9) for acceptable cut offs of stability reliability, and the number of monitoring days necessary to achieve these ICC values were 3, 5, and 11 days, respectively.

Table 2.1 presents a brief summary of studies which reported the number of monitoring days required for the monitoring of free-living PA in both adults and children using hip-worn AMs.

Table 2.1. Summary of free-living physical activity reliability studies for hip-worn AMs

Population Age	Lead Author	Year	Activity Monitor	Total Monitoring Days	Desired ICC	Monitoring Days to Reach ICC
Adult	Coleman	1998	TriTrac, T	7	0.77- 0.82	3-4
Adult	Mattews	2002	CSA, U	21	0.8	3-4
Children (7-15)	Janz	1995	CSA, U	6	0.7	4
Children (7-12)	Trost	2000	CSA, U	7	0.7	3*
					0.8	5*
					0.9	11*
Adolescent (13-18)	Trost	2000	CSA, U	7	0.7	5*
					0.8	9*
					0.9	20*
Children (8-9)	Trueth	2003	CSA, U	4	0.8	7
Children (13-14)	Murray	2004	Actigraph, U	7	0.8	5-6
Children (11)	Mattocks	2008	Actigraph, U	7	0.7	3*
					0.8	5*
					0.9	11*

T= triaxial, O = omnidirectional, * indicates value was rounded to the nearest whole day

Monitor Placement

Although the hip has been established as the most common site AMs are worn during physical activity monitoring in various populations (Ward et al. 2005; Trost et al. 2005), investigation has been made into the placement of AMs on different locations for various reasons in adult and youth populations (Heil 2006; Heil et al. 2009; Leenders et al. 2003; Melanson and Freedson 1995; Swartz et al. 2000). Research performed by Melanson and Freedson (1995) investigated the use of wrist and ankle AMs in combination with a hip-worn monitor to determine if additional monitors improved the accuracy of estimated EE during treadmill walking and jogging in adults. The researchers concluded that the use of three monitoring locations more accurately predicted EE than did the hip location alone. Swartz et al. (2000) examined the combination of a wrist- and hip-worn AM to estimate EE during simulated free-living activities in adults. Though the combination of the monitors statistically improved the estimate of EE, the authors questioned the practically of the combination as there were only limited improvements in the estimate of EE. Although small improvements of the estimation of EE have been documented with the use of multiple AMs during activity monitors, Trost et al. (2005) suggested that these small improvements do not justify the increased burden placed on participants.

The ability of wrist- and ankle-worn AMs to estimate EE has also been evaluated independent of hip-worn monitors. Leenders et al. (2003) studied a uniaxial AM worn at the wrist and ankle to determine if these locations could more accurately estimate EE than a hip-worn monitor during various treadmill walking speeds in adults. Bodily

movement measured by wrist and ankle monitors explained 28% and 27%, respectively, of the variance associated with estimations of EE. These results indicate that when wrist and ankle locations are utilized independent of a hip-worn AM, the ability of the wrist and ankle monitors to estimate EE were considerably lower. However, a study by Heil (2006) showed promising results using an omnidirectional AM worn at the wrist and ankle by adults and children. During treadmill locomotion and simulated free-living activities ankle-worn AMs monitors in children and adults explained 60% and 43%, respectively, of the variance associated with the estimate of activity energy expenditure (AEE), while wrist-worn monitors explained 69% in children and 75% in adults. Puyau et al. (2002) investigated the use of two models of AMs, an omnidirectional and unidirectional monitor. Both types of AMs were worn at hip and lower leg locations to estimate AEE in children (6-16 yrs). Counts recorded by the unidirectional monitor worn at the hip and lower leg were reported to explain 75% and 82%, respectively, of the variance associated with the estimation of AEE. The omnidirectional monitor worn at the hip and lower leg was reported to explain 81% and 71 %, respectively, of the variance associated with the estimation of AEE. Table 2.2 summarizes related literature performed with alternative monitoring locations.

Table 2.2. Summary of alternative locations used to monitor physical activity in a lab setting

Population Age Range	Lead Author	Year	Activity Monitor	Criterion Measure	Analysis Method	Monitor Location	Validity Results
Adult	Melanson	1995	CSA, U	EE	R	W	0.86
						W, A	0.94
						H, W	0.94
						H, W, A	0.95
Adult	Swartz	2000	CSA, U	EE	R	H, W	0.343
						H	0.317
						W	0.33
Adult	Leenders	2003	CSA, U	EE	R	W	0.28
						A	0.27
Adult	Heil	2006	Actical, O	AEE	R	H	0.67
						W	0.75
						A	0.43
Children (8-16)	Heil	2006	Actical, O	AEE	R	H	0.73
						W	0.69
						A	0.6
Children (6-16)	Puyua	2002	CSA, U	AEE	CC	H	0.75
						LL	0.82
			Actiwatch, B	AEE		H	0.81
						LL	0.71

U = uniaxial, O = omnidirectional, B = biaxial, *indicates value was rounded to whole day, EE = energy expenditure, AEE = activity energy expenditure, R = regression, CC = correlation coefficient, H = hip, W = wrist, A = ankle, LL = lower leg

Recently, the use of wrist and ankle-worn AM to monitor PA during free-living conditions was studied. The use of omnidirectional AMs was assessed to predict free-living PA in adults. The variables of physical activity (CNT_{MV}, T_{MV}, AEE_{MV}) measured by the AM were found to be dependent on monitor location and definition of bout duration. When PA variables were measured from wrist and ankle AM locations there was a tendency for outcome variables to differ significantly from variables measured at the hip (when measured at 1-min bout duration). However, as bout duration increased to 10 minutes there were no significant differences in PA variables between the wrist, ankle, and hip monitoring locations (Heil, Bennett, Bond, Webster, and Wolin 2009).

As research continues regarding the ability of wrist- and ankle-worn AMs to accurately measure free-living PA, the need to establish the reliability of AMs at the wrist and ankle locations becomes pertinent. Webster and Heil (2008) examined the stability reliability of PA variables measured by omnidirectional wrist-worn AMs in an adult population. It was reported that to reach an acceptable level of stability reliability (ICC of 0.80) for PA variables, activity counts from MVPA ($CTN_{MV)}$, AEE from MVPA ($AEE_{MV)}$, and time spent in MVPA (T_{MV}), the necessary monitoring days ranged from 10-12, 5-8 and 3-5, respectively. Presently, there have been no investigations of the stability reliability for habitual physical activity variables measured by a wrist-worn AM in a youth population.

Summary

Accelerometry-based monitors have been established as an objective measuring tool to examine the habitual free-living PA behavior of children. To reliably measure habitual free-living PA with AMs there are many factors which should be considered before determining the necessary amount of monitoring days. The number of monitoring days can vary due to factors such as population age, days of the week included in the monitoring period, seasonal variation of PA, the operational definition for acceptable reliability, and monitor placement on the body. Currently, the number of monitoring days recommended to obtain reliable measurements of habitual PA outcome variables in children when AMs are worn at the hips is 4-9 days.

Currently the hip location is the most common site for AMs to be worn during PA monitoring studies. The research which has been performed into alternative locations has mostly focused on the use of additional AMs locations to improve estimates of EE; however there have been a small number of studies that have investigated the use of wrist and ankle AMs independent of the hip. The validation of these alternative locations has begun to build; currently there is very limited knowledge of the stability reliability of PA outcome variables measured from wrist- and ankle-worn AMs. While the stability reliability of omnidirectional wrist-worn AMs to measure habitual free-living PA variables has been examined in adults, no investigation of their use has been performed in youth thus far.

CHAPTER THREE

STABILITY RELIABILITY OF HABITUAL PHYSICAL ACTIVITY WITH THE ACTICAL® ACTIVITY MONITOR IN A YOUTH POPULATION

Contribution of Authors and Co-Authors

Chapter 3

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Contributions: Assisted with study design, implemented data collection, processed and analyzed data, and wrote manuscript.

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Contributions: Dr. Daniel Heil conceived the study design, assisted with data processing and analysis, discussed results and implications, and was primary editor of the manuscript at all stages. Dr. Mary Miles and Dr. John Seifert discussed study design, results and implications of the study, as well as reviewed and commented on the complete manuscript.

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Abstract

The purpose of this study was to examine and compare stability reliability of hip- and wrist-worn activity monitor (AM) physical activity (PA) outcome variables for adolescents (12-17 years) under free-living conditions. Twenty-one adolescents (11 girls, 10 boys) wore AMs at hip and wrist locations for a 14 consecutive day monitoring period. The dependent variables were total time (minutes/day) occurring at sedentary (T_S), light (T_L) and ≥ moderate (T_{MV}) intensity PA, and the sum of activity energy expenditure (AEE; kcals/day) occurring at a light (AEE_L), ≥ moderate intensity (AEE_{MV}) and from total AEE for a monitoring day (AEE_T). Intraclass correlation coefficients for each monitoring day (ICC_{DAY}) were calculated to examine reliability of all dependent variables for both AM locations, over bout durations of 1-, 5-, and 10-minutes. Excluding T_L measured by the wrist AM location, ICC_{DAY} values for all variables decreased as bout duration increased from 1- to 10-minutes. The number of monitoring days to reach an $ICC_{DAY} \geq 0.80$ for AEE_L, AEE_{MV}, AEE_T, T_L and T_{MV} across all three bout durations was higher for hip- versus wrist-worn AM, and ranged from 2-26 versus 2-10 days, respectively. Conversely, then number of monitoring days to reliably measure T_S was lower for hip AM (4-5 days) versus the wrist AM (6-8 days) locations. Among all the variables, T_L had the largest range of necessary monitoring days to reach an $ICC_{DAY} \geq 0.80$, 7-10 and 6-26 days across all bout durations for the wrist and hip, respectively. Further comparison of the dependent variables by day type revealed that only T_L measured at the wrist had significantly different means on weekdays versus weekends (p-value ≤ 0.001) across all bout durations. While not significant, mean values for T_{MV}, AEE_{MV}, and AEE_T measured by both hip- and wrist-worn AMs, were higher on weekdays than on weekends. In summary, reliability of time and AEE PA variables was dependent on bout duration and AM location. Generally, to reliability measure free-living PA in adolescents wrist-worn AMs required fewer monitoring days than hip-worn AMs.

Introduction

Participation in habitual physical activity (PA) has been shown to lower the risk of developing chronic illness such as cardiovascular disease, diabetes, and obesity in children and adults (Warburton et al. 2006; Pate et al. 1995). As childhood obesity rates remain alarmingly high (Ogden, Carroll, and Curtin 2010), more importance has been placed on the beneficial relationship between PA and the reduction of health risks. Current U.S. Federal guidelines, suggest that children and adolescents should participate in at least 60 minutes of PA daily (US Department of Health and Human Services [USDHHS] 2008). However, in order to gain a better understanding of the dose-response benefits associated with PA and the appropriateness of current PA, researchers and clinicians must have an objective means of measuring habitual free-living PA.

Accelerometry-based activity monitors (AM) have emerged as an objective method for measuring PA. Activity monitors are advantageous due to the small size of the devices, long-term storage capacity, and the ability to measure intensity, frequency, and duration of PA (Heil 2006). When considering the need to understand behavioral choices of exercise, the measurement of time and frequency spent at specific PA intensities allows for an objective comparison of the observed PA behaviors to current PA guidelines. Several studies have reported acceptable validity of AMs to measure PA within the youth population, allowing for AMs to be established as valid tools for the assessment of PA within this population (Puyau et al. 2004; Freedson et al. 1998; Trost et al. 1998; Heil 2006; Pfeiffer et al. 2006).

The number of monitoring days necessary to achieve reliable measurements of free-living PA variables has been studied for hip-worn AMs in youth (Janz et al. 1995; Mattocks et al. 2008; Trueth et al. 2003; Trueth et al. 2004; Trost et al. 2000;). A review by Trost et al. (2005) recommended 4-9 consecutive AM monitoring days for children. The range of monitoring days is a composite of recommendations reported by multiple studies that differed in population parameters and methodological choices made by researchers. When choosing the number of monitoring days it is important to consider factors that affect the stability reliability of PA variables such age, the types of days included in the monitoring period (e.g. weekend versus weekdays), the operational definition of acceptable reliability, and the AM wearing location.

The influence of age on the reliability of PA variables has been investigated within different youth age ranges. Trost et al. (2000) compared the stability reliability between adolescents (grades 7-12) and children (grades 1-6) for hip-worn accetlerometry-based AMs over a 7-day period. The ICC values for 7 days of monitoring ranged from 0.76 to 0.77 for adolescents and 0.86 to 0.87 for children. Types of days included in the monitoring period, such as weekdays versus weekends, can also influence stability reliability. Studies in youth have indicated a significant difference between habitual moderate to vigorous PA (MVPA) performed on weekdays versus weekends (Metcalf et al. 2002; Trost et al. 2000). Additionally, the operational definition of acceptable reliability has been shown to produce multiple recommendations for the necessary number of monitoring days within a youth population (Janz et al. 1995; Mattocks et al. 2008; Treuth et al. 2004; and Trost et al. 2000). Mattocks et al. (2008) provided an

example of how the required number of monitoring days can change based on the variation of operational definition for acceptable reliability within the same groups of individuals. Three ICC values were chosen (ICC = 0.70, 0.80, 0.90) for acceptable levels of stability reliability, and the number of monitoring days necessary to achieve these ICC values were 3, 5, and 11 days, respectively.

Monitor wearing location is an additional methodological decision which should be considered when using AMs. Currently, the hip location is the most common site for AMs to be worn during PA monitoring studies (Ward et al. 2005; Trost et al. 2005). Research of alternative locations has mostly focused on the use of additional AMs locations to improve estimates of EE (Melanson and Freedson 1995; and Swartz et al. 2000). Although small improvements of the estimation of EE have been documented with the use of multiple AMs during activity monitors, Trost et al. (2005) suggested that these small improvements do not justify the increased burden placed on participants. However, a small number of studies have investigated the use of wrist- and ankle-worn AMs independent of a hip-worn AM (Leenders et al. 2003; Heil 2006; and Puyau et al. 2002). Specifically, Heil (2006) reported that omnidirectional AMs explained 60% and 69% of the variance associated with the estimation of AEE during treadmill locomotion and simulated free-living activities in children when worn at the ankle and wrist, respectively.

Recently, the same type of omnidirectional AM worn at wrist and ankle locations was used to predict free-living PA in adults (Heil, Bennett, Bond, Webster, and Wolin 2009). Physical activity variables (CNT_{MV}, T_{MV}, AEE_{MV}) measured by wrist- and ankle-worn AMs differ significantly from variables measured by hip-worn AM when measured

with a 1-min bout duration. However, as bout duration increased to 10-mins there was no significant differences in PA variables between the wrist-, ankle-, and hip-worn AM locations (Heil, Bennett, Bond, Webster, and Wolin 2009).

As research continues regarding the ability of wrist- and ankle-worn AMs to accurately measure free-living PA, the need to establish the reliability of AMs at alternative locations becomes pertinent. Webster and Heil (2008) examined the stability reliability of PA variables measured by omnidirectional wrist-worn AMs in adults. It was reported that an acceptable level of stability reliability (ICC of 0.80) for the variables of time spent within MVPA (T_{MV}) and AEE from MVPA (AEE_{MV}) ranged from 3-5 and 5-8 days of continuous monitoring, respectively.

Presently, there have been no investigations of the stability reliability for habitual PA variables measured by a wrist-worn AM in a youth population. The purpose of this study was to examine and compare the stability reliability of wrist- and hip-worn activity monitor PA outcome variables in adolescents (12-17 yrs) under free-living conditions. The PA outcome variables of interest for this study were time within sedentary, light, and MV physical activity intensities (T_S, T_L, T_{MV}) and AEE from light, MV, and total PA (AEE_L, AEE_{MV}, AEE_T).

Methods

Participants and Procedures

Adolescents (12-17 years) from Bozeman, Montana, volunteered to participate in this study. Subjects read and signed an informed consent document, approved by the

Montana State University Human Subjects Review Committee, explaining the requirements and risks of the study. Additionally, because all subjects were minors, consent by a legal guardian was necessary for participation. Subjects wear asked to wear both wrist- and hip-worn AMs for 14 consecutive days. Subjects met with the investigator prior to the start of the monitoring period at the Montana State University (MSU) Movement Science Teaching Lab (MSTL) in Bozeman, Montana, and again at the end of the monitoring period at a convenient location chosen by each subject.

During the first lab visit subject demographics such as age, gender, height and body mass were recorded. Height and body mass for each subject were measured to the nearest 0.1 cm and kg, respectively (Health-o-Meter® PRO Series, Pelstar LLC, Alsip, IL). Additionally, all subjects received two AMs and a small blank note book to be used as a personal log book. All AMs were calibrated to collect at 15-sec epochs and initialized to start at 3:00 am the morning following the first lab visit. Participants were instructed to carry out their usual free-living activities during the 14 consecutive monitoring days.

For the initial donning of the AMs, the investigator instructed participants how to wear each monitor. The wrist-worn AM was located proximal to the ulnar styloid, on the dorsal side of the wrist of choice, using a locking plastic wristband. After the wristband was locked into place the AM could only be removed by cutting the wristband. The wrist-worn AM was placed on the wrist at the end of the initial lab visit, and participants were instructed to wear the wrist monitors continuously for the entire monitoring period. Each participant was given supplemental wristbands to use in case there was need to remove

the original wristband for any reason. Subjects were asked to record such wearing issues in their log book and to contact the investigator with any questions. A second hip-worn AM was mounted on a plastic clip so that the AM could be worn at the beltline of clothing. Participants were instructed to wear the hip-worn AM on the beltline, just anterior to the iliac crest of the right hip and aligned with the anterior-axially line of the thigh. During the initial lab visit participants were shown the proper position of the hip-worn AM, and asked to start wearing it upon waking the next morning.

With the exception of removing the hip AM during swimming, showering, and sleeping, participants were instructed to wear the hip-worn AM for a minimum of 12 consecutive hours daily. To account for times during which hip-worn AMs were removed, participants were asked to record the date, time, and reason (i.e., swimming, showering, or sleeping) for taking off the AM in their log book. In an effort to increase compliance of wearing behavior for hip-worn AMs, subjects were shown an example printout of AM data that showed the difference in output for when the monitor was being worn or not worn.

The morning after the first meeting subjects were contacted by phone, email or text message to remind them to begin wearing the hip AM. Additional contact was made to participants every 2-3 days during the 14-day monitoring period to help keep participants engaged in the study, as well as increase compliance. Participants were instructed to contact the investigator if any problem arose during the monitoring period. Fifteen days after the initial lab meeting, the investigator met with subjects to collect the AMs and log books.

Instrumentation

The Actical® activity monitor (Philips Respironics, Inc., Bend, OR) was used for PA monitoring at both the wrist and hip locations. The Actical® is a small (2.8 cm x 2.7 cm x 1.0 cm^3), lightweight (17 g), water resistant omnidirectional accelerometry-based AM. Although the monitor is omnidirectional, it is most sensitive to acceleration along a single axis (uniaxial), the orientation of which is indicated by a star symbol on the upper left face of the monitor. Wrist-worn AMs were worn so the sensitive axis was perpendicular to the ground when the subject's wrist hung at their side. Similarly, the hip-worn AMs were worn so that the most sensitive axis was perpendicular to the ground and ran parallel to the anterior-axially line of the thigh. For the purpose of this study, 42 Actical® monitors were used for PA monitoring.

Data Screening and Processing

Hip- and wrist-worn AM raw data for each subject were screened prior to data analysis. Data for all monitoring days for each subject were visually evaluated for technical errors and compliance issues. Additionally, AM data for each individual were compared to the individual's log book. Although monitors were worn for a 14-day monitoring period, only 11 days and 8 hours of activity data was collected due to the AM memory becoming saturation. Thus, only 11 days were considered for the monitoring period of each subject. For a day to be considered part of an individual's monitoring period the data files for both hip and wrist locations were required to meet the following criteria: 1) The monitor was worn for 10 consecutive hours between the first and last blasts of activity for the day; 2) The maximum non-wear time during a monitoring day

was < 120 minutes; 3) A monitoring day with a period of non-wear time ≥ 120 minutes was only considered part of the monitoring period if total wear time was ≥ 10 hours. Days that did not meet these criteria were eliminated from an individual's monitoring period. Since subjects started monitoring on different days of the week, the raw Actical® data were reorganized so that all monitoring periods consisted of five consecutive weekdays (Day 1-5), followed by two consecutive weekend days (Day 6-7), with the remanding days placed in chronological order following Day 7. All data files were then reduced from15-sec epochs to 60-sec epochs by summing four successive 15-sec epoch values, to allow for evaluation of data in terms of counts/min.

Prior to the transformation of the data from raw counts to AEE, all wrist files were smoothed using a previously reported smoothing algorithm (Heil, Hymel and Martin 2009). A custom Visual Basic (Version 6.0; Microsoft Corporation, Redmond, WA) computer program was then used to convert data files from both wrist- and hip-worn AMs for each subject to minute-by-minute activity energy expenditure (AEE, kcals/kg/min). The equations used to convert raw activity data to AEE were double regression model algorithms (2R) validated at the wrist and hip in children (8-16 yr) during simulated free-living activities and locomotion (Heil 2006). The algorithms used to determine AEE are based on a four step process that is established on cut points of raw activity data and are summarized in Table 3.1.

Table 3.1. Summary of Heil's (2006) double regression model algorithms (2R) for converting raw activity monitor output to activity energy expenditure (AEE) in children.

Location	CP1	CP2	AEE constant when 50 < AC < CP1	Predicted AEE when CP1 ≤ AC ≤ CP2	Predicted AEE when AC ≥ CP2
Hip	300	1,650	0.0113	AEE = 0.01667 + (5.103E-5) x AC	AEE = 0.03534 + (1.135E-5) x AC
Wrist	900	2,000	0.0113	AEE = 0.01149 + (3.236E-5) x AC	AEE = 0.03115 + (1.581E-5) x AC

AC = activity monitor output (counts/min); CP1 = lower AC cut point; CP2 = upper AC cut point; AEE = activity energy expenditure (kcals/kg/min)

After data files were transformed into units of AEE, each file was searched for predetermined bout durations (one, five, and ten consecutive minutes) for all PA outcome variables (Heil, Bennett, Bond, Webster and Wolin 2009). The AEE cut point used to classify sedentary activity was < 0.015 kcals/kg/min, light activity was ≥ 0.015 kcals/kg/min and < 0.05 kcals/kg/min, moderate activity was ≥ 0.05 kcals/kg/min and < 0.10 kcal/kg/min, whereas vigorous activity was considered to be an AEE ≥ 0.10 kcal/kg/min (Payau et al., 2002). Physical activity outcome variables of time (T_S, T_L, T_{MV}) and AEE (AEE_L, AEE_{MV}, AEE_T) were then calculated over the various bout durations for both monitoring locations, during a single monitoring day for each subject.

Statistical Analyses

All statistical procedures were conducted using Statistix (Version 9.0, Analytical Software, Tallahassee, FL). Mean and standard deviation were calculated for subject demographics, as well as average wear time for both wrist- and hip-worn AMs. Mean and

standard error (SE) values were then calculated for all dependent variables (T_S, T_L, T_{MV} and AEE_L, AEE_{MV}, AEE_T) across all bout durations (1-, 5-, 10-mins). Differences between day type (weekday versus weekend) for each dependent variable, wear time of hip-worn AM, and bout length were then examined using a two-factor (Subject x bout) multivariate repeated measures analysis of variance (RMANOVA), followed by Sheffe's post-hoc for all-pairwise comparisons (α =0.05). Stability reliability for both AM wearing locations at the various bout durations was examined by calculating ICC values specific to single days (ICC_{DAY}) within the monitoring period. Comparison of ICC_{DAY} values allowed for examination of how stability reliability of PA outcome variables was affected by AM location and bout duration in an adolescent population.

Intraclass correlation coefficient values were calculated by using a two-factor (Subject x Days) RMANOVA, for both wrist- and hip-worn AMs at each of the three bout durations. The ANOVA tables were then used to calculate ICC values for the entire monitoring period for all dependent variables, for both the wrist- and hip-worn AMs. Where ICCs were calculated as:

$$\text{ICC} = \frac{\sigma_w^2 - \sigma_b^2}{\sigma_w^2}$$

where σ_w^2 is the within-subject variance and σ_b^2 is the between-subject variance. This latter term was calculated as:

$$\sigma_b^2 = \frac{SS_{DAY} + SS_{ERROR}}{DF_{DAY} + DF_{ERROR}}$$

where SS_{DAY} and SS_{ERROR} are the sum of squares values, and DF_{DAY} and DF_{ERROR} are the degrees of freedom values from the ANOVA tables.

Intraclass correlation coefficients for a specific day (ICC_{DAY}) were then calculated for the entire monitoring period for both monitor locations. For the dependent variables where ICC_{DAY} values did not reach the desired value ≥ 0.8 within the 11 day monitoring period, the number of days was extended until a predicated ICC ≥ 0.8 was reached. ICC_{DAY} was calculated by:

$$ICC_{DAY} = \frac{\sigma_w^2 - \sigma_b^2}{\sigma_w^2 + [(N/N') - 1)] * (\sigma_b^2)}$$

where N is the number of days in the monitoring period, and N' is the number of days for which an ICC value is being calculated.

In addition to using ICC_{DAY} values to investigate stability reliability, 95% confidence intervals (CI) were also calculated for all ICC_{DAY} values. The 95% CIs were calculated as suggested by Morrow and Jackson (1993), and used to determine if any significant differences existed between the stability reliability of time and AEE variables by monitor location (e.g., non-overlapping CIs).

Results

The demographics for twenty-one study participants (11 girls, 10 boys) are summarized in Table 3.2.

Table 3.2. Subject demographic characteristics (Mean ± SD).

	N	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)
Girls	11	13.9 ± 1.6	155.7 ± 8.7	46.8 ± 9.1	19.1 ± 2.18
Boys	10	14.9 ± 2.1	171.1 ± 10.9	63.0 ± 10.8	21.5 ± 2.3
All Subjects	21	14.4 ± 1.9	163 ± 12.4	54.5 ± 12.8	22.2 ± 2.5

Wear Time and Monitor Period Duration

All subjects were asked to wear both wrist and hip AMs for 14 consecutive days, however due to memory saturation of the AMs only 11 full monitoring days were recorded during the monitoring period. Wear time for the monitors was calculated by visually examining graphs of the raw activity output, and manually counting hours of wear time per day. Days that did not meet the inclusion criteria for a monitoring day were excluded from the calculation of wear time. With the exception of one subject, wrist-worn AMs were reported to be worn continuously (24 hrs/day) for the full duration of the monitoring period by all subjects. The one subject reported removing both the wrist-worn and hip-worn AMs for participation in a competitive basketball game. By examining the raw activity counts of the wrist and hip AM and the subject's log book it was determined that the AMs for this subject were removed for a two hour period on two monitoring days. Wear time for hip-worn AMs had considerably more variability than that for the wrist-worn monitors due to non-wear time. Average wear time for the hip-worn AMs for weekdays, weekends, and all monitoring days is reported in Table 3.3. Average wear

time was observed to be slightly higher (35 min) on weekdays versus weekends, however this difference was not statistically significant (p-value= 0.07).

Table. 3.3. Average wear time (hours/day) for hip-worn AMs (Mean ± SD).

	Weekday	Weekend	All Monitoring Days
Wear Time (hours/day)	14.3 ± 0.8	13.7 ± 0.3	14.0 ± 0.3

Descriptive Statistics and
Intraclass Correlation Coefficients

Duration of monitor period between wrist- and hip-worn AMs varied due to the amount of usable monitoring days obtained by each subject. Since all subjects had 11 full days that met the outlined criteria of a monitor day, an 11-day monitoring period was used for analysis at the wrist. In contrast, only 12 subjects had 11 full days of hip monitoring, and all 21 subjects had at least nine full days of monitoring. Thus, a 9-day monitoring period was used for analysis of the hip-worn AM data. Mean and standard error values for variables of time and AEE by day type and bout duration are presented in Tables 3.4, 3.5, 3.6, and 3.7. Intraclass correlation coefficient values and associated 95% CIs for all dependent variables (T_S, T_L, T_{MV} and AEE_L, AEE_{MV}, AEE_T) across all three bout durations for both monitor locations are summarized in Tables 3.8 – 3.11.

Table 3.4. Descriptive statistics (Mean ± SE) for time (min/day) variables for hip-worn activity monitors by bout duration. All statistics are based upon pooled values from specific type of monitoring days used in the analyses.

PA Variable	Type of Day	Minimum Bout Duration 1-min	5-min	10-min
T_S	Weekday	1164.0 ± 16.1	1078.6 ± 19.4	990.5 ± 21.6
	Weekend	1171.6 ± 19.1	1084.4 ± 22.4	997.6 ± 23.1
	Total	1170.4 ± 6.5	1083.0 ± 7.9	996.1 ± 8.9
T_L	Weekday	183.9 ± 9.4	42.2 ± 4.5	7.6 ± 1.6
	Weekend	196.0 ± 11.4	50.5 ± 6.5	12.4 ± 2.8
	Total	185.4 ± 4.1	43.5 ± 2.1	8.7 ± 1.0
T_{MV}	Weekday	92.1 ± 10.4	34.5 ± 6.7	17.7 ± 3.9
	Weekend	72.4 ± 11.7	24.0 ± 9.1	12.8 ± 6.1
	Total	84.2 ± 4.1	30.4 ± 3.0	15.9 ± 2.3

Note: The means of all dependent variables varied significantly across bout durations, T_S = Time within sedentary intensity; T_L = Time within light intensity; T_{MV} = Time within moderate and vigorous intensities

Table 3.5. Descriptive statistics (Mean ± SE) for time (min/day) variables for wrist-worn activity monitors by bout duration. All statistics are based upon pooled values from specific type of monitoring days used in the analyses.

PA Variable	Type of Day	Minimum Bout Duration 1-min	5-min	10-min
T_S	Weekday	677.7 ± 20.7	619.4 ± 19.7	561.0 ± 17.3
	Weekend	741.6 ± 21.2	685.0 ± 20.9	620.1 ± 19.0
	Total	699.3 ±7.8	641.9 ± 7.8	580.8 ± 7.3
T_L*	Weekday	628.4 ± 16.1	526.0 ± 17.5	409.0 ± 20.4
	Weekend	573.3 ± 15.7	466.5 ± 16.2	345.1 ± 16.8
	Total	613.9 ± 6.2	509.6 ± 6.7	390.2 ± 7.4
T_{MV}	Weekday	133.9 ± 16.1	84.3 ± 12.6	44.1 ± 7.9
	Weekend	125.1 ± 20.6	80.5 ± 17.2	41.9 ± 10.8
	Total	126.8 ± 5.5	79.8 ± 4.5	41.7 ± 3.2

Note: The means of all dependent variables varied significantly across bout durations, T_S = Time within sedentary intensity; T_L = Time within light intensity; T_{MV} = Time within moderate and vigorous intensities, * = Significant difference between weekday and weekend for all bout durations.

Table 3.6. Descriptive statistics (Mean ± SE) for activity energy expenditure (kcals/day) variables for and hip-worn activity monitors by day type and bout duration. All statistics are based upon pooled values from specific type of monitoring days used in the analyses.

PA Variable	Type of Day	Minimum Bout Duration 1-min	5-min	10-min
AEE_L	Weekday	201.5 ± 17.4	47.9 ± 6.3	9.2 ± 2.1
	Weekend	214.9 ± 19.5	56.5 ± 8.0	13.6 ± 3.0
	Total	202 ± 6.5	48.6 ± 2.7	9.7 ± 1.1
AEE_{MV}	Weekday	380.1 ± 57.7	156.1 ± 34.7	83.4 ± 20.0
	Weekend	286.8 ± 56.0	105.5 ± 40.2	59.0 ± 28.0
	Total	345 ± 20.9	136.8 ± 14.3	74.1 ± 11.1
AEE_T	Weekday	581.6 ± 72.3	207.1 ± 38.4	92.5 ± 21.1
	Weekend	501.7 ± 70.3	162.0 ± 43.7	72.6 ± 28.3
	Total	546.9 ± 25.3	185.4 ± 15.1	83.9 ± 11.3

Note: The means of all dependent variables varied significantly across bout durations, AEE_L = Activity energy expenditure (kcals/day) at a light intensity; AEE_{MV} = Activity energy expenditure (kcals/day) at or above a moderate intensity; AEE_T = Activity energy expenditure from total activity

Table 3.7. Descriptive statistics (Mean ± SE) for activity energy expenditure (kcals/day) variables for and wrist-worn activity monitors by day type and bout duration. All statistics are based upon pooled values from specific type of monitoring days used in the analyses.

PA Variable	Type of Day	Minimum Bout Duration 1-min	5-min	10-min
AEE_L	Weekday	481.7 ± 27.6	394.3 ± 22.1	297.4 ± 18.1
	Weekend	446.14 ± 20.4	353.2 ± 15.7	254.6 ± 11.8
	Total	474.7 ± 8.7	385.2 ± 7.4	287.2 ± 6.3
AEE_{MV}	Weekday	569.9 ± 95.1	378.2 ± 71.0	211.0 ± 44.7
	Weekend	504.0 ± 108.14	346.0 ± 87.8	191.7 ± 57.1
	Total	531.69 ± 30.4	356.3 ± 24.2	200.7 ± 17.5
AEE_T	Weekday	1051.6 ± 116.0	773.0 ± 83.7	508.8 ± 52.8
	Weekend	950.1 ± 119.6	699.7 ± 93.9	446.8 ± 59.7
	Total	1006.4 ± 36	741.93 ± 27.8	488.4 ± 19.7

Note: The means of all dependent variables varied significantly across bout durations , AEE_L = Activity energy expenditure (kcals/day) at a light intensity; AEE_{MV} = Activity energy expenditure (kcals/day) at or above a moderate intensity; AEE_T = Activity energy expenditure from total activity

Table 3.8. Intraclass correlation coefficients (ICC) with 95% confidence intervals (CI) for time variables (minutes/day) derived from the wrist-worn activity monitor, and the number of monitoring days necessary to reach a specific ICC value.

		ICC Values and 95% CI			Monitoring Days to Achieve Reliability		
Variable	Bout (min)	Day 5	Day 7	Day 11	0.70	0.80	0.90
T_S	1	0.78 0.53 – 0.91	0.83 0.63 – 0.93	0.89 0.74 – 0.95	4	6	13[a]
	5	0.76 0.49 – 0.90	0.82 0.60 – 0.92	0.88 0.72 – 0.95	4	7	14[a]
	10	0.73 0.43 – 0.88	0.79 0.54 – 0.91	0.85 0.67 – 0.94	5	8	17[a]
T_L	1	0.69 0.36 – 0.86	0.75 0.48 – 0.89	0.83 0.62 – 0.93	6	10	21[a]
	5	0.69 0.37 – 0.87	0.76 0.48 – 0.90	0.80 0.62 – 0.93	6	9	21[a]
	10	0.75 0.47 – 0.89	0.81 0.58 – 0.92	0.87 0.7 – 0.95	4	7	15[a]
T_{MV}	1	0.89 0.74 – 0.95	0.92 0.8 – 0.97	0.95 0.87 – 0.98	2	3	6
	5	0.88 0.72 – 0.95	0.91 0.76 – 0.96	0.94 0.86 – 0.98	2	3	7
	10	0.81 0.58 – 0.92	0.86 0.68 – 0.94	0.90 0.78 – 0.96	3	5	11

[a] Predicted number of days; T_S = Time within sedentary intensity; T_L = Time within light intensity; T_{MV} = Time within moderate and vigorous intensities

Table 3.9. Intraclass correlation coefficients (ICC) with 95% confidence intervals (CI) for time variables (minutes/day) derived from the hip-worn activity monitor, and the number of monitoring days necessary to reach a specific ICC value.

		ICC Values and 95% CI			Monitoring Days to Achieve Reliability		
Variable	Bout (min)	Day 5	Day 7	Day 9	0.70	0.80	0.90
T_S	1	0.85 0.65 – 0.94	0.88 0.73 – 0.95	0.91 0.78 – 0.96	3	4	9
	5	0.82 0.60 – 0.92	0.86 0.69 – 0.94	0.89 0.74 – 0.96	3	5	10[a]
	10	0.81 0.59 – 0.92	0.86 0.68 – 0.94	0.89 0.74– 0.95	3	5	11[a]
T_L	1	0.78 0.53 – 0.91	0.83 0.63 – 0.93	0.87 0.70 – 0.94	5	6	13
	5	0.71 0.40 – 0.87	0.78 0.52 – 0.90	0.82 0.59 – 0.92	5	9	19[a]
	10	0.44 0.01 – 0.73	0.52 0.11 – 0.78	0.58 0.20 – 0.81	16[a]	26[a]	59[a]
T_{MV}	1	0.87 0.69 – 0.94	0.90 0.77 – 0.96	0.92 0.81 – 0.97	3	4	9
	5	0.85 0.65 – 0.94	0.88 0.73 – 0.95	0.91 0.78– 0.96	3	4	9
	10	0.76 0.50 – 0.90	0.82 0.60 – 0.92	0.85 0.67 – 0.94	4	7	14[a]

[a] Predicted number of days; T_S = Time within sedentary intensity; T_L = Time within light intensity; T_{MV} = Time within moderate and vigorous intensities

Table 3.10. Intraclass correlation coefficients (ICC) with 95% confidence intervals (CI) for activity energy expenditure variables (kcals/day) derived from the wrist-worn activity monitor, and the number of monitoring days necessary to reach a specific ICC value.

		ICC Values and 95% CI			Monitoring Days to Achieve Reliability		
Variable	Bout (min)	Day 5	Day 7	Day 11	0.70	0.80	0.90
AEE_L	1	0.93 0.83 – 0.97	0.95 0.87 – 0.98	0.97 0.92 – 0.99	1	2	4
	5	0.89 0.74 – 0.95	0.92 0.80 – 0.97	0.95 0.87 – 0.98	2	3	6
	10	0.81 0.59 – 0.92	0.86 0.68 – 0.94	0.91 0.78 – 0.96	3	5	11
AEE_{MV}	1	0.92 0.81 – 0.97	0.94 0.86 – 0.98	0.96 0.91 – 0.99	1	2	4
	5	0.90 0.77 – 0.96	0.93 0.83– 0.97	0.95 0.89– 0.98	2	3	5
	10	0.85 0.67 – 0.94	0.89 0.74 – 0.96	0.93 0.83 – 0.97	3	4	8
AEE_T	1	0.94 0.86 – 0.98	0.96 0.90 – 0.98	0.97 0.93 – 0.99	1	2	3
	5	0.93 0.83 – 0.97	0.95 0.87 – 0.98	0.97 0.92 – 0.99	1	2	4
	10	0.89 0.74– 0.95	0.92 0.80 – 0.97	0.95 0.87 – 0.98	2	3	6

[a] Predicted number of days; AEE_L = Activity energy expenditure (kcals/day) at a light intensity; AEE_{MV} = Activity energy expenditure (kcals/day) at or above a moderate intensity; AEE_T = Activity energy expenditure from total activity

Table 3.11. Intraclass correlation coefficients (ICC) with 95% confidence intervals (CI) for activity energy expenditure variables (kcals/day) derived from the hip-worn activity monitor, and the number of monitoring days necessary to reach a specific ICC value.

		ICC Values and 95% CI			Monitoring Days to Achieve Reliability		
Variable	Bout (min)	Day 5	Day 7	Day 9	0.70	0.80	0.90
AEE_L	1	0.91 0.78 – 0.96	0.93 0.84 – 0.97	0.95 0.87 – 0.98	2	3	5
	5	0.80 0.55 – 0.91	0.84 0.65 – 0.94	0.87 0.71 – 0.95	4	6	12[a]
	10	0.56 0.17 – 0.80	0.64 0.28– 0.84	0.69 0.37 – 0.87	10[a]	16[a]	36[a]
AEE_{MV}	1	0.91 0.78 – 0.96	0.93 0.84 – 0.97	0.95 0.87 – 0.98	2	3	5
	5	0.86 0.68 – 0.94	0.89 0.75 – 0.96	0.92 0.80 – 0.97	2	4	8[a]
	10	0.72 0.43 – 0.89	0.79 0.54 – 0.91	0.83 0.61 – 0.93	5	8	18[a]
AEE_T	1	0.93 0.82 – 0.97	0.95 0.87 – 0.98	0.96 0.90 – 0.98	1	2	4
	5	0.88 0.72 – 0.95	0.91 0.79 – 0.96	0.93 0.83 – 0.97	2	3	7
	10	0.78 0.53 – 0.91	0.83 0.62 – 0.93	0.86 0.69 – 0.94	4	6	13[a]

[a] Predicted number of days; AEE_L = Activity energy expenditure (kcals/day) at a light intensity; AEE_{MV} = Activity energy expenditure (kcals/day) at or above a moderate intensity; AEE_T = Activity energy expenditure from total activity

Mean values for AEE_L, AEE_{MV}, AEE_T, T_L and T_{MV} were higher when measured from the wrist versus the hip AM location. Time within sedentary intensity (T_S) was the only variable that had higher mean values for the hip-worn versus the wrist-worn AM. Comparison of the dependent variables by bout duration and day type revealed that while means for all variables were significantly different across bout durations (1-, 5- and 10-mins.), only means for T_L measured at the wrist were significantly different on weekdays versus weekends (p-value ≤ 0.001). While not significant, mean values for T_{MV}, AEE_{MV}, and AEE_T measured by both hip- and wrist-worn AMs, were higher on weekdays than on weekends. Conversely, mean values for T_S measured at both monitoring locations were higher on the weekend versus the weekdays. Trends for means of T_L and AEE_L differed by monitor location. Mean values of T_L and AEE_L measured by the hip AM location were higher on the weekend versus weekdays, whereas means measured by the wrist AM location were higher on weekdays versus the weekend.

No significant differences in ICC_{DAY} values were found between wrist- and hip-worn AM locations for any of the dependent variables (i.e., overlapping confidence intervals). However, there were distinct trends in ICC_{DAY} values for both time and AEE variables. For example, the ICC_{DAY} values for T_S tended to be higher at the hip than the wrist for a given number of monitor days (e.g., 5, 7, and 9) at all three bout durations. The variable of T_L had higher ICC_{DAY} values at the hip than the wrist with a bout duration of 1- and 5-minutes, and a lower value with the bout duration of 10-mins. The ICC_{DAY} values for T_{MV} were higher at the wrist versus the hip across all three bout durations. Additionally, the number of days necessary to reach an ICC value (0.7, 0.8,

and 0.9) was greater as bout duration increased for all wrist and hip variables, except for the hip variable T_L were the number of necessary days decreased.

Distinct trends were also observed for AEE variables measured by wrist and hip AM locations (Tables 3.10 and 3.11). For the variables of AEE_L, AEE_{MV}, and AEE_T, ICC_{DAY} values were higher for wrist-worn AMs than hip-worn AMs for all days in the monitoring period (e.g., 5, 7, and 9). The number of days necessary to reach an acceptable ICC_{DAY} value increased with bout duration for all AEE variables measured at both monitoring locations. Furthermore, the magnitude of this increase was greater for hip-worn AM variables than for wrist-worn AM variables. For example, the necessary days to reach an ICC $\geq$ 0.80 for AEE_{MV} across bout durations of 1-, 5-, and 10-mins for the wrist AM were 2, 3, and 4 days, respectively, while 3, 4, and 8 days were required at the hip.

Table 3.12 summarizes the number of days needed to reach an ICC $\geq$ 0.80 over all three bout durations for time and AEE variables at both AM locations. The number of days to reach an acceptable ICC ($\geq$ 0.80) for T_S and T_{MV} were similar between AM location, ranging from 3–8 and 4–7 days for the wrist and hip, respectively. In comparison the variable of T_L tended to need a greater number of monitoring days for both the wrist-worn (7-10 days) and hip-worn AM (6-26 days), with the highest number of days being required for T_L measured by hip-worn AM with a10-min bout duration. Variables of AEE measured by wrist-worn AMs had higher reliability values. The necessary number of days for all wrist AEE variables (AEE_L, AEE_{MV}, AEE_T) ranged from 2–5 days, while all hip AEE variables required 2–16 days.

Table 3.12. Number of days needed to reach an ICC ≥ 0.80 for each variable across all bout durations for wrist and hip monitoring locations.

	Dependent Variables		
Monitor Location	T_S	T_L	T_{MV}
Wrist	6 – 8	7 – 10	3 – 5
Hip	4 -5	6 – 26[a]	4 – 7
	AEE_L	AEE_{MV}	AEE_T
Wrist	2 – 5	2 – 4	2 – 3
Hip	3 – 16[a]	3 – 8	2 – 6

[a] Predicted number of days; AEE_L = Activity energy expenditure (kcals/day) at a light intensity; AEE_{MV} = Activity energy expenditure (kcals/day) at or above a moderate intensity; AEE_T = Activity energy expenditure from total activity; T_S = Time within sedentary intensity; T_L = Time within light intensity; T_{MV} = Time within moderate and vigorous intensities

Discussion

Previous research has established the reliability of accelerometry-based AMs to measure habitual free-living PA in youth (Janz et al. 1995; Mattocks et al. 2008; Murray et al. 2004; Trueth et al. 2003; Trost et al. 2000). However, past research has focused solely on the stability reliability of PA outcome variables when measured by hip-worn AMs. Only recently has stability reliability of free-living PA variables been reported for alternative monitor locations in an adult population (Webster and Heil 2008). The purpose of the current study was to examine and compare the stability reliability of both wrist- and hip-worn AM locations for variables of time and AEE, with hope of expanding current recommendations and practices for using alternative AM locations during free-living PA monitoring in adolescents. Additionally, all PA variables were examined across three distinct minimum bout durations (1-, 5-, 10-min) to facilitate the comparison of stability reliability for PA outcome variables to current PA guidelines.

Summary of Differences
between AM Locations

Stability reliability of all AEE variables (AEE_L, AEE_{MV}, AEE_T) was higher for wrist-worn versus hip-worn AMs across all bout durations (1-, 5-, and 10-mins). The differences observed between monitor locations for time variables was not as clear, thus reliability recommendations are greatly dependent on the PA outcome variable and bout durations of interest. Less monitoring days were required to reach an ICC of 0.80 for T_S when measured at the hip versus the wrist location, across all bout durations. However, for T_{MV} a greater number of days were required at the hip than the wrist location. The variable of T_L showed less reliability for wrist-worn than hip-worn AMs for 1-bout durations, however as bout duration increased to 5- and 10-min higher reliability was seen at the wrist location.

To reliably measure (ICC $\geq$ 0.80) the PA outcome variable of T_S, T_L, T_{MV} across the bout durations of 1-, 5-, and 10-mins the necessary number of monitoring days ranged from 3-10 days at the wrist and 4-26 days at the hip. The days necessary to reliably measure variable of AEE_L, AEE_{MV}, and AEE_T over the same three bout durations would require 2-5 and 2-16 days at the wrist and hip, respectively.

When relating the results of activity monitoring PA outcome variables to current PA guidelines, the most direct comparison can be made when variables are analyzed with minimum 10-min bout duration. Taking this into consideration the stability reliability for the majority of the dependent variables (T_L, T_{MV}, AEE_L, AEE_{MV}, and AEE_T) was higher for wrist-worn versus hip-worn AMs with a bout-duration of 10-mins. The one exception to this was the T_S variable, which had higher ICC_{DAY} values for the hip versus the wrist

location. However, on a practical note T_S measured at the wrist reached an ICC_{DAY} value of 0.79 on the 7th day of monitoring.

Hip-worn Activity Monitor

Results from the current study indicate that 2-8 days were necessary to reach an ICC ≥ 0.80 for the variables T_{MV}, T_S, AEE_{MV} and AEE_T when measured by both AM locations, across all bout durations. This range is similar to the current recommendation of 4-9 monitoring days for youth populations (Trost et al. 2005). While the recommended range of days for PA monitoring includes reliability results of time and count variables, it is limited by the ranges of reported intensities, bout durations, the hip location, and does not include reliability of AEE variables. For example, Trost et al. (2000) reported 4-5 days and 8-9 days were necessary to reach an ICC of 0.80 for time spent in MVPA in children and adolescents, respectively, however the reliability results are limited to a bout duration of 1-min, and the variable time spent within MVPA. Similarly, while Janz et al. (1995) reported that 5-6 days were needed to reliably measure frequency of counts/day spent within sedentary, moderate, and vigorous intensities of PA in adolescents, the reliability results are limited to the variable of counts/day and are specific to the intensity cut points used in this study.

Although PA guidelines are recommended in bout durations lasting longer than 10 minutes (USDHHS 2008), examination of the effect of bout duration ($\geq$1-min) for the stability reliability for free-living PA variables has not yet been reported in youth. However, recently the effect of bout duration on the stability reliability of PA variables was investigated for hip-worn AMs in adults (Webster and Heil 2008). It was observed

that stability reliability for the variables of T_{MV} and AEE_{MV}, decreased as bout duration increased from 1-min to 10-min bouts. A similar trend in the current study was observed for all time variables (T_S, T_L, T_{MV}) and AEE variables (AEE_L, AEE_{MV}, AEE_T) measured by hip-worn AMs (Tables 3.9 and 3.11).

Wrist-worn Activity Monitor

While the ability of wrist-worn AMs has been reported to acceptably measure locomotion and stimulated free-living PA in children (Heil 2006; Puyau et al. 2002); the stability reliability of wrist-worn AMs has not been reported in youth, and has only rarely been reported in adults (Webster and Heil 2008). Currently, there are no recommendations for the number of monitoring days required to reliably measure PA outcome variables with wrist-worn AMs in youth. The results from the current study indicate that for the variables of T_{MV}, AEE_L, AEE_{MV} and AEE_T the number of monitoring days necessary to reach an ICC $\geq$ 0.80, across all three bout durations, ranged from 2-5 days. The variables of T_S and T_L required a slightly greater number of monitoring days, 6-8 and 7-10 days, respectively. However, in general wrist dependent variables, across all bout durations, fell within the current recommendations made for activity monitoring at the hip (4-9 days) in a youth population.

The current reliability results for wrist-worn variables are similar to those reported by Webster and Heil (2008) although comparison is limited to the variables of T_{MV} and AEE_{MV}. The number of days to reach an ICC $\geq$ 0.80 for T_{MV} was observed to be similar between adolescents and adults (3-5 days). Whereas a difference in the number of monitoring days to reach an ICC $\geq$ 0.80 was observed for AEE_{MV}, 2-4 days and 5-8

days for adolescents and adults, respectively. Currently, longer duration monitoring periods are recommended for youth (4-9 days) versus adults (3-5 days), due to greater variations in daily PA levels (Trost 2005). Thus, it was expected that PA variables measured by wrist-worn AMs would require more monitoring days for adolescents than for adults, however the opposite was observed. This discrepancy may be attributed to the additional processing step applied to wrist-worn AM data in the current study. A smoothing algorithm was used to reduce the "activity noise" often observed with AM output from wrist-worn AMs. This additional step was taken because results from a previous study indicated that when the smoothing algorithm was applied AEE (kcals/day) measured at the wrist correlated moderately well with actual AEE measured by doubly labeled water (Heil, Hymel and Martin 2009). The smoothing algorithm may have allowed for a more accurate representation of PA outcome variables measured by wrist-worn AMs. The greater accuracy of measurement could have decreased the amount of variability and lead to increased stability reliability for the PA outcome variables.

Measurement of Light Intensity Physical Activity

The variables of T_L and AEE_L measured by hip-worn AMs had the largest range of required days to reach an ICC $\geq$ 0.80 across bout durations, 6-26 and 3-16 days, respectively. The decreases in reliably across bout durations may be a reflection of adolescents' behavior of time spent within a light intensity, pointing towards a trend of adolescents to spend less time in sustained blocks of light intensity PA.

However, this observation may also point towards a limitation of hip-worn AMs to measure PA within light intensities. Although much attention has been placed on the ability of hip-worn AM to reliably measure habitual MVPA, considerably less focus has been placed on the capacity of these AMs to reliably measure sedentary to light intensity PA. Matthews et al. (2002) reported the stability reliably of minutes/day for both MVPA and physical inactivity measured by hip-worn AMs in a healthy adult population. Inactivity in this study was defined as activity requiring < 3 METS and thought to be representative of sitting and stationary standing activities (e.g., dusting, cooking, and washing dishes). The results of the study indicated that while counts/day of MVPA reached an ICC of 0.80 in 3-4 monitoring days, the variable of counts/day of physical inactivity was less reliable and required 7 days of monitoring. The sources of variance (intra-individual vs. inter-individual) for the different PA intensities were also investigated. It was reported that the greatest source of variance for min/day in MVPA was inter-individual (53-57% of total), meaning that the majority day-to-day MVPA differences were due to differences between study participants. However, for physical inactivity the greatest source of variance for min/day in physical inactivity was intra-individual (55-57%), signifying that the majority day-to-day physical inactivity differences observed were due to differences within study participants (Matthews et al. 2002).

An additional explanation for lower stability reliability observed at light intensity for hip-worn AMs may be related to low intra-instrument reliability of the AMs. In a stimulated free-living setting, similar trends of decreased reliability at light intensity PA

were recently observed with hip-worn omnidirectional AMs, over repeated bouts of PA in adolescents. Vanhelst et al. (2010) reported that the coefficient of variation (CV %) for counts/min decreased as PA intensity increased: 17.3% for sedentary intensity, 16.2% for light intensity, 9.5% for moderate intensity, and 6.6% for vigorous intensity. Specific to the Actical®, Heil (2006) reported lower intra-instrument reliability (R_{XX}) for hip-worn AM output during light intensity seated activities in children. The lower reliability reported at light intensity may be a limitation of the calibration algorithm used in the current study. The calibration algorithm used to process the data relies on two established cut points (CP) (Table 3.1.). Cut point 1 differentiates between light-intensity sitting activities and moderate-intensity cleaning activities, whereas the second CP differentiates between cleaning and locomotion tasks. However, there is a less distinguishable CP for light-intensity activity and sedentary activity. Currently, a constant is used when activity counts are < 50 counts/min (0.0113 kcal/kg/min), due to poor predictability of AEE below this threshold and inconsistent AM output during seated activities (Heil 2006). As interest grows regarding the health outcomes of physical inactivity, it becomes vital for researchers to develop and clarify the ability of AMs to measure intensities at the lower end of the PA spectrum.

While the hip-worn AMs in the current study required a greater number of days to reliably measure T_L and AEE_L, this trend was not observed at the wrist. Traditionally the hip-wearing location has been used because of its close proximity to the body's center of mass. However, it has been suggested that the hip location cannot accurately detect free-living types of activities that utilize the upper body (Swaterz et al. 2000). Recently, the

accuracy of wrist-, ankle-, and hip-worn Actical® AMs to predict free-living PA outcome variables over bout durations ranging from 1 to 10-mins were examined in adults. It was reported that while T_{MV} and AEE_{MV} from the wrist-worn AM were over predicted when compared to the variables measured by a full body monitoring system (IDEEA) at bout durations of 1-3 minutes, these differences diminished at higher bout durations. Similarly, T_{MV} and AEE_{MV} measured at the wrist were significantly different when measured at the hip with a 1-min bout duration. However, as bout duration increased to 10-mins there was no significant differences in PA variables between the wrist- and hip-worn AM locations (Heil, Bennett, Bond, Webster, and Wolin 2009). These results along with the reliability results of the current study indicate that the wrist may offer a valid and reliable alternative monitoring location for the measurement of free-living PA in adolescents.

Potential Sources of Variation

Stability reliability expressed as an ICC_{DAY} value is a ratio of the inter- and intra-subject variances associated with the measurement of the PA outcome variables. The investigation of potential sources of variation may allow for a better understanding of the differences observed in stability reliability for dependent variables. The level of habitual PA measured on weekdays versus weekend days has been reported as a potential source of variation in youth. Trost et al. (2000) reported adolescents (grades 7-12) exhibited significantly lower levels of time spent within MVPA on weekends compared to weekdays. Although not significant, similar trends were observed in the current study. In the current study T_{MV}, AEE_{MV}, and AEE_{T} measured by both the wrist and hip AM location were observed to have lower mean values on weekends versus weekdays.

The variable T_L measured from wrist-worn AM locations was the only variable that showed a significant difference between weekdays and weekends (p-value ≤ 0.001). Additionally, mean values for T_L and AEE_L were the only variables that differed by monitor location. Mean values for T_L and AEE_L measured by the hip AM location across all bout durations, were higher on the weekend versus weekdays. Whereas mean values of T_L and AEE_L measured by the wrist AM location were lower on the weekend versus weekdays. The discrepancy between mean trends observed by day type for AM location for the variables T_L and AEE_L may relate to the ability of the AMs to accurately assess light intensity PA.

The difference in mean wear time for hip-worn AMs was examined between weekdays and weekends. Wear time for weekdays was observed to be 35 minutes higher than wear time on weekends, a difference which approached significance (p-value = 0.07). However, because distinct differences in means by type of day were observed for both monitoring locations, wear time variation is thought to be less influential when compared to actual differences in PA behavior between weekdays and weekends.

An additional source of variation may have been from the difference of total number of monitoring days between wrist- and hip-worn AMs. Low compliance of the hip-worn AM during the monitoring period can lead to loss of data. Decreased wear time of hip AMs in the current study led to the decision to reduce the total number of monitoring days from 11 to 9 days, so that all 21 subjects could be included in the analyses. The difference in total number of days between the wrist-and the hip-worn AMs, (11 versus 9 days, respectively) may have created a potential source of variation in

the calculation of ICC values. Intraclass correlation coefficient values specific to a given number of monitoring days (e.g., 5, 7, and 9) were calculated using the same variance values reported for the total number of days in the monitoring period, 11days for the wrist AM and 9 for the hip AM. The difference in number of monitoring days between AM locations highlights a limitation of the equation used to calculate subsequent ICC_{DAY} values, because the equation assumes that variance day-to-day variance is equal. Potentially, there was a larger variance associated with the hip AM location because of fewer monitoring days, which may have lead to variation independent of AM location alone.

Conclusions

The stability reliability results of this study indicate the need for *a priori* decisions to be made regarding the PA outcome variables, bout duration, and AM location of interest. Generally, stability reliability values were higher, although not significant, for wrist-versus hip-worn AMs in adolescents. The number of monitoring days to reach an ICC $\geq$ 0.80 for time and AEE variables across all bout durations, ranged from 2-10 days and 2-26 days, when measured by wrist- and hip-worn AMs, respectively. Practically, the results from the current study indicate that a monitoring period of 7 days allows for wrist-worn AMs to reliably measure time and AEE outcome variables with a 10-min bout duration in adolescents under free-living conditions.

CHAPTER FOUR

CONCLUSIONS

Intraclass correlation coefficients were used to examine and compare stability reliability for the variables T_S, T_L, T_{MV}, AEE_L, AEE_{MV} and AEE_T, across bout durations (1-, 5-, 10-mins) for both wrist- and hip-worn AMs in adolescents under free-living conditions. Generally, stability reliability values were higher, although not significant, for wrist-versus hip-worn AMs. The necessary number of monitoring days to reach an ICC ≥ 0.80 for time and AEE variables across all bout durations, ranged from 2-10 days and 2-26 days, when measured by wrist- and hip-worn AM locations, respectively.

The reliability results of this study indicate the need for *a priori* decisions to be made regarding the PA outcome variables, bout duration, and AM location of interest. These decisions must be made prior to data collection in order to determine an appropriate monitoring period duration which will allow for a reliable measurement habitual free-living PA. Practically, the results from the current study indicate that a monitoring period of 7 days allows for wrist-worn AMs to reliably measure time and AEE outcome variables with a 10-min bout duration in adolescents under free-living conditions.

While the results from this study showed promising results for the ability of wrist-worn AMs to reliably measure free-living PA variable in adolescents, several assumptions were made that limit the current results. First, while the ability of Actical® AMs to measure free-living PA by wrist- and hip-worn AMs across multiple bout

durations has been established in adults it has yet to be established in adolescents. Similarly, the smoothing algorithm used to process the wrist AM data was limited to results for an adult population. Thus, while it was assumed that results from these previous studies would be similar between adult and adolescent populations further research is needed to establish these specific parameters in an adolescent population.

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APPENDIX A

SUBJECT CONSENT FORM

SUBJECT CONSENT FORM
FOR PARTICIPATION IN HUMAN RESEARCH
MONTANA STATE UNIVERSITY

PROJECT TITLE: *Stability Reliability of Habitual Physical Activity with the Actical® Activity Monitor in a Youth Population*

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PURPOSE OF THE STUDY:

The 2008 Federal Physical Activity Guidelines for Americans currently recommends that all children and adolescence participate in at least 60 minutes of physical activity daily to promote a healthy lifestyle. Researcher and clinicians often use devices called accelerometry-based activity monitors to measure and record an individual's physical activity. These activity monitors help researchers to measure frequency, intensity, and duration of physical activity. Activity monitors are most commonly worn on the hip; however there is growing interest in how well activity monitors measure physical activity when worn at the wrist. Specifically, researchers are interested in determining the number of days a wrist-worn monitor must be worn to accurately reflect an individual's regular physical activity pattern. Currently, researchers have investigated how many days are necessary to wear a wrist-worn activity monitor to measure regular physical activity in adults, but not in adolescence.

The purpose of this study is to determine the number of days a wrist-worn and hip-worn accelerometer must be worn by an adolescent to accurately measure their level of physical activity. To accomplish this goal, each participant will be required to wear two accelerometers, one at the wrist and one at the hip, for 14 consecutive days while continuing normal daily physical activities.

If you agree to participate, you will be asked to wear two activity monitors, one worn at the wrist and one worn at the hip, for 14 consecutive days.

- The wrist-worn monitor will be worn 24 hours per day for all 14 days. The monitors that will be used are waterproof and considered safe to wear during activities such as bathing and swimming.

- The hip-worn monitor will be worn during all hours while you are awake (a minimum of 12 hours per day), expect during activities such as showering, swimming, and sleeping.

STUDY PROCEDURES:

Participation is voluntary. If you agree to participate, you will meet ***twice*** with the investigator. The first visit will be held at the Movement Science Teaching Lab (MSTL) on the second floor of Romney Building on the campus of Montana State University. The first visit will last about 60 minutes. The second meeting will be at a convenient location for you, and will take about 15 minutes.

FIRST MEETING: During the first meeting you will be asked to fill out paperwork (Informed Consent), and have your age, gender, body weight, and body height recorded. You will then be given two activity monitors to be worn on the wrist and the hip.

- The activity monitor worn on the wrist will be secured with a plastic band. The band will be loose enough for comfort, but snug enough that the monitor cannot move freely around the wrist. **Once the wrist monitor is placed on the wrist it should be worn 24 hours/day for the next 14 days.** Once locked, the wrist band can only be removed by cutting the plastic**.** You will be given two extra plastic bands in case the band size needs to be adjusted due to discomfort, or the original band needs to be replaced during the 14 days. The activity monitors are waterproof and considered safe to wear during activities such as bathing, and swimming.

- The activity monitor worn on the hip will be worn at the belt line towards the front of the hip. **This activity monitor is to be worn during all waking hours (a minimum of 12 consecutive hours).** The monitor will be worn with a clip and should be removed only for showering, swimming, and sleeping.

You will also be provided with a notebook which you will be asked to record the times the hip-worn activity monitor is taken off and put on during the 14 days. For example, you would record when you put the monitor on in the morning when you get up, or when you take it off to shower.

14 DAY MONITORING PERIOD: After the first visit, you will be required to wear both the hip and wrist activity monitors for 14 consecutive days. During the 14 days you will be expected to carry out daily activities as usual. The investigator is **not** interested in the **amount** of physical activity that you participate in, but rather how well the activity monitor **records the physical activity you already participate in**. Thus, you should continue with daily activities as if the monitors were not being worn.

You will be contacted by the investigator by phone, e-mail, or text the day after the first visit as a reminder to wear the hip-worn activity monitor. Additionally, you will be contacted every few of days (2-3) during the 14 day monitoring period as a reminder to wear the hip monitor.

THE FINAL MEETING: The final meeting will take place 15 days after the first visit. The investigator will arrange a final meeting with you for the 15th day, at a location that is convenient for you. During the final meeting the investigator will collect your two activity monitors and your notebook. This time will also be used to discuss any problems you may have faced during the monitoring. The final visit will take about 15 minutes, and will end your participation in the study.

POTENTIAL RISKS:
There are no known risks associated with participation in this study.

BENEFITS:
There are no direct benefits for participants in this study. However, each participant can request a copy of the study results, as well as a printout of your own accelerometer wearing data, by contacting the Project Director, Katelyn Taylor, by phone (360) 510-2311 or E-mail (katelynjtaylor@gmail.com).

STUDY PARTICIPANT COMPENSATION:
You will be offered $30.00 compensation for completing the full 14 day s of monitoring, OR be offered the opportunity to donate the $30.00 directly to the Bridger Ski Foundation. You are free to withdraw from the study before the end of the 14 day period; however you will not receive any partial compensation.

CONFIDENTIALITY:
The data and personal information obtained from this project is confidential. The information will not be released except upon your written request. All data will be analyzed using coded identification for each person's data so that privacy is maintained.

FREEDOM OF CONSENT:
You may withdraw consent for participation in writing, by telephone, or in person without prejudice or loss of benefits (as described above). Please contact Katelyn J. Taylor, by phone (360) 510-2311 or E-mail (katelynjtaylor@gmail.com), or the lab director Daniel P. Heil by phone (406-994-6324) or E-mail (dheil@montana.edu), to discontinue participation. *Participation in this project is completely voluntary*.

In the UNLIKELY event that your participation in this project results in physical injury to you, the investigators will refer you to a trained caregiver, however, there are no funds available for such treatment. *Further information regarding medical treatment may be obtained by calling Katelyn J. Taylor at (360) 510-2311.*

You are encouraged to express any questions, doubts or concerns regarding this project. The investigators will attempt to answer all questions to the best of their abilities prior to any testing. The investigators fully intend to conduct the project with your best interest, safety and comfort in mind. *Additional questions about the rights of human subjects can be answered by the Chairman of the Human Subjects Committee, Mark Quinn, at 406-994-4707.*

PROJECT TITLE: ***Stability Reliability of Habitual Physical Activity with the Actical® Activity Monitor in a Youth Population***

STATEMENT OF AUTHORIZATION

Since you, the participant, are **less than 18 years of age** at the time this study, you MUST have the consent of a parent or legal guardian as indicated by their signature below.

I have read the above and understand the discomforts, inconveniences and risks of this study. I, _____ *(name of parent or guardian),* related to the subject as _____ *relationship,* agree to the participation of _____ *(name of subject)* in this research. I understand that the subject or I may later refuse participation in this research and that the subject, through his/her own action or mine, may withdraw from the research at any time. I have received a copy of this consent form for my own records.

Signed:_____ Date:_____

Participant's Assent Signature

Signed:_____ Date:_____

Parent or legal Guardian

Signed: **_____*Date:*_____**

Investigator